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FORM PTO-1390 (Modified) (REV 10-95) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: 226333

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR): 09/381328

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/US98/05174	17 March 1998	18 March 1997

TITLE OF INVENTION

METHOD AND APPARATUS FOR SUPRRESSION OF THE GLOW-TO-ARC TRANSITION IN GLOW DISCHARGES

APPLICANT(S) FOR DO/EO/US

Kunhardt, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☒ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
    A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☐ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☒ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Response dated April 7, 1999, to Written Opinion with amendment to claims.

FOR VALUE ACCOUNTABILITY
DEPOSIT ACCOUNT NO.
06 2143

FEE CODE	VALUE PURCHASED
957	335
962	96

PCTUS1/REV03

420 Rec'd PCT/PTO 17 SEP 1999

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
09/381328	PCT/US98/05174	226333

20. The following fees are submitted:	CALCULATIONS PTO USE ONLY	
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :		
☐ Search Report has been prepared by the EPO or JPO **$840.00**		
☒ International preliminary examination fee paid to USPTO (37 CFR 1.482) **$670.00**		
☐ No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) **$760.00**		
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO **$970.00**		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) **$96.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	**$670.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$130.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	23 - 20 =	3	x	$18.00	**$54.00**
Independent claims	4 - 3 =	1	x	$78.00	**$78.00**
Multiple Dependent Claims (**check if applicable**).			☐		**$0.00**

TOTAL OF ABOVE CALCULATIONS =		**$932.00**
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (**check if applicable**).	☒	$932.00 ~~$466.00~~
SUBTOTAL =		**$466.00**
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +		**$0.00**
TOTAL NATIONAL FEE =		**$466.00**
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (**check if applicable**).	☒	**$40.00**
TOTAL FEES ENCLOSED =		$972.00 ~~$506.00~~
Amount to be: refunded		$
charged		$

☒ A check in the amount of **$506.00**, $466.00 to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees.
A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **06-2143** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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33,884
REGISTRATION NUMBER

16 September 1999
DATE

Attorney's Docket No. 226333

Applicant: Kunhardt, et al.

For: Method and Apparatus for Suppression of the Glow-to-Arc Transition in Glow Discharges

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) AND 1.27(c)) - SMALL BUSINESS CONCERN

I hereby declare that I am an official of the small business empowered to act on behalf of the concern identified below:

Stevens Institute of Technology
Castle Point on Hudson
Hoboken, NJ 07030

I hereby declare that the above-identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time. part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention,

entitled: Method and Apparatus for Suppression of the Glow-to-Arc Transition in Glow Discharges

by: Kunhardt, et al.

described in: PCT Application No. PCT/US98/05174 filed on March 17, 1998.

If the rights held by the above-identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below, and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Name: _____

Address: _____

___individual ___small business concern ___nonprofit organization

Name: _____

Address: _____

___individual ___small business concern ___nonprofit organization

I acknowledge the duty to file, in this application or patent, notification of any changes in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate (37 CFR 1.28(b)).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Name of person signing: Joseph J. Moeller, Jr.

Title of person signing: Vice President for the Graduate School and Research Services

Address of person signing: Stevens Institute of Technology, Castle Point on the Hudson, Hoboken, New Jersey 07030

Signature: _____ Date: 10/28/99

Joseph J. Moeller, Jr.

forms/smntb333.226

GLOW PLASMA DISCHARGE DEVICE

SPECIFICATION

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention generally relates to a method and apparatus for the suppression of the glow-to-arc transition in DC and RF glow discharges. and more specifically to a cathode configuration having a perforated dielectric covering for stabilizing glow plasma discharges.

RELATED ART

A "plasma" is a partially ionized gas composed of ions, electrons, and neutral species. This state of matter is produced by high temperatures or strong electric fields created by constant or pulsed DC current, AC current or time varying (e.g., R.F. or microwave) electromagnetic fields. Discharge plasmas are produced when free electrons are energized by electric fields in a background of neutral atoms / molecules. These electrons cause electron - atom / molecule collisions which transfer energy to the atoms / molecules and form a variety of species which may include photons, metastables, atomic excited states, free radicals, molecular fragments, monomers, electrons, and ions. The neutral gas becomes partially (or fully) ionized and is able to conduct currents. The plasma species are chemically active and/or can physically modify the surface of materials and may therefore serve as the basis of new chemical compounds and may be used to modify existing compounds. Discharge plasmas can also produce useful amounts of optical radiation and can therefore be used in lighting. There are additionally many other uses for such plasmas. Glow discharges and arc discharges produce a class of plasmas known as current-maintained plasmas, since they are maintained by the passage of current therethrough. Such plasmas conduct only because current is passed therethrough and the conductivity falls off quickly if the source of energy to the charge carriers is removed.

Transition points exist at which the various attributes of the discharge and discharge plasma change from the characteristics of a glow discharge to the characteristics of an arc discharge. The characteristics that distinguish arc from glow are a high gas temperature and a low cathode fall potential, though it is also possible to have a high gas temperature associated with a high cathode fall and vice versa.

The transition from glow to arc passes through a series of stable or quasi-stable states. However, the final step from abnormal glow to arc is very often an unstable change, since a very large potential drop in the series resistance would be required to make it stable. If there is no series resistance, the transition may take place very rapidly, without equilibrium being achieved in any intermediate stage. This transition becomes more rapid as the pressure of the background neutral gas increases towards atmospheric pressure.

In the past, there have been efforts to stabilize glow plasma discharges in various ways such as the use of source frequencies over 1 kHz, insertion of a dielectric plate (or plates) between two metal electrodes and by using helium dilution gas. Additionally, other attempts to stabilize the glow plasma discharge include placement of an insulated plate on the lower electrode, use of a brush-style upper electrode, and the use of a metal upper plate in combination with an insulating plate on the bottom thereof. However, there are certain drawbacks with these requirements in that, e.g. helium is expensive and there are physical limitations based on the structure of the electrodes and the insulated plates.

Past work in this area include a series of articles by Okazaki, Satiko, et al., starting back in 1989 with the article by Kanazaw, S., et al., entitled, "Glow Plasma Treatment at Atmospheric Pressure for Surface Modification and Film Deposition," Nuclear Instruments and Methods in Physics Research (1989) Elsevier Science Publishers, B.V. (North-Holland Physics Publishing Division), which disclosed a plasma treatment at atmospheric pressure to stabilize glow plasma by treatment in a gas which includes carbon-tetrafluoride (CF_4), using helium as the dilute gas and using an insulating plate on a lower electrode, and using a brush style electrode for the upper electrode to create a stable discharge at 3,000 Hz.

Yokoyama, T., et al., "The improvement of the atmospheric-pressure glow plasma method and the deposition of organic films," Journal of Physics (1990) IOP Publishing, Ltd., discloses an improved atmospheric pressure glow discharge plasma method for treating metallic substrates wherein the middle plate upper electrode is improved by use of an insulating plate set on its bottom.

Yokoyama, T. et al., "The mechanism of the stabilization of glow plasma at atmospheric pressure," Journal of Physics (1990) IOP Publishing, Ltd., discloses stabilization of a glow discharge of atmospheric pressure by controlling three conditions, namely, the use of a high frequency source, the use of helium gas for dilution, and the insertion of a dielectric plate between electrodes.

Okazaki, Satiko, et al., "Appearance of stable glow discharge in air, argon, oxygen, and nitrogen at atmospheric pressure using a 50 Hz source," Journal of Physics, (1993) IOP Publishing, Ltd., discloses a method and apparatus for stabilizing glow discharge by making the discharge occur in the early stages of the Kekez curve, and at a lower discharge breakdown voltage, by use of a metal wire mesh electrode.

Kogoma, Masuhiro, et al., "Raising of ozone formation efficiency in a homogeneous glow discharge plasma at atmospheric pressure," Journal of Physics (1994) IOP Publishing, Ltd., discloses an ozone formation apparatus for increasing the efficiencies of ozone formation by use of a homogenous glow discharge at atmospheric pressure to create ozone efficiencies increased to about 10% in air to a maximum of 15% in oxygen over conventional filamentary current discharges in gas. The increase is attributed to better collision efficiency among electrons and molecules and to a lower increase in temperature than in discharge filaments of a silent electric discharge.

Other work in this area includes U.S. Patent No. 4, 498,551 to Hoag, entitled, "Discharge Electrode for a Gas Discharge Device," which uses pin-shaped electrodes which are effectively cooled in the glass flow and which promote a stable glow-discharge.

U.S. Patent No. 5,387,842 dated February 7, 1995 to Roth, et al., entitled, "Steady-State, Glow Discharge Plasma," and U.S. Patent No. 5,414,324 dated May 9, 1995 to Roth, et al., entitled "One Atmosphere, Uniform Glow Discharge Plasma," both disclose a steady state glow discharge plasma generated between a pair of insulated metal plate electrodes spaced up to five centimeters apart and energized with a RMS potential of 1 to 5 KV at 1 to 100 Khz. The space between the electrodes is occupied by a noble gas such as helium, neon, argon, etc., and it may also include air. The radio frequency amplifier means for generating and maintaining a glow discharge plasma includes an impedance matching network. The arc of electric field is high enough to trap the positive ions of the plasma between the electrodes, but not so high that the electrons of the plasma are also trapped during a half cycle of the RF voltage.

None of these previous efforts disclose all of the benefits of the present invention, nor does the prior art teach or suggest all of the elements of the present invention.

OBJECTS AND SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a method and apparatus for stabilizing glow discharge plasmas.

It is another object of the present invention to provide a method and apparatus for suppressing the glow-to-arc transition in glow discharges.

It is an additional object of the present invention to provide a method and apparatus to stabilize glow discharge plasmas in a constant electric field.

It is even an additional object of the present invention to provide a method and apparatus to stabilize glow discharge plasmas in time varying electric fields.

It is another object of the invention to provide a cathode configuration for stabilizing the cathode fall in a glow discharge.

It is an additional object of the present invention to provide a method and apparatus for suppressing the glow-to-arc transition for a wide range of operating conditions and a wide range of operating pressures.

It is another object of the present invention to provide a metal cathode covered with a perforated dielectric for suppressing the glow-to-arc transition and stabilizing glow discharge.

It is also an object of the present invention to provide a method and apparatus for suppressing the glow-to-arc transition for a wide range of electric field strengths.

It is an additional object of the present invention to tailor the characteristics of fuel combustion by field augmentation with suppression of the glow-to-arc transition.

It is an additional object of the present invention to tailor the characteristics of plasma assisted materials processing by suppressing the glow-to-arc transition in material processing.

It is another object of the present invention to suppress the glow-to-arc transition and to allow for large volume plasma work at atmospheric pressure.

It is an additional object of the present invention to reduce the complexity and costs of plasma processing of materials.

It is even a further object of the present invention to improve pollution control through the use of plasmas at high pressures by suppressing the glow-to-arc transition.

These and other objects are achieved by the method and apparatus of the present invention for stabilizing glow plasma discharges by suppressing the transition from glow-to-arc. A dielectric plate having an upper surface and a lower surface and a plurality of holes extending therethrough is positioned over the cathode and held in place thereon by a collar. Each of the holes acts as a separate active current limiting micro-channel that prevents the overall current density from increasing above the threshold for the glow-to-arc transition.

BRIEF DESCRIPTION OF THE DRAWINGS

Other important objects and features of the invention will be apparent from the following Detailed Description of the Invention when read in context with the accompanying drawings in which:

FIG. 1 is an exploded perspective view of the perforated dielectric covering a cathode of a DC embodiment of the present invention.

FIG. 2 is a schematic view of a circuit configuration for use with the present invention.

FIG. 3 is a graph of voltage v. current for applied voltage, glow voltage, and arc voltage in Argon at 40 Torr.

FIG. 4 is a graph of voltage v. current for applied voltage, glow voltage, and arc voltage in Argon at 20 Torr.

FIGS. 5a and **5b** are graphs of applied voltage, glow voltage and arc voltage with and without the perforated dielectric of the present invention.

FIG. 6a is a photograph showing an arc discharge and **FIG 6b** is a photograph showing a glow discharge.

FIG. 7 is a side plan view of another embodiment of the present invention for an RF field wherein perforated dielectrics are positioned over both electrodes.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a method and apparatus for stabilizing plasma glow discharges by suppressing the glow-to-arc transition in DC, RF electric field, pulsed DC, AC current or any other glow discharges which evolves from the cathode fall region. Referring to **FIG. 1**, it can been seen that a new cathode configuration has been developed to stabilize the cathode fall and suppress the glow-to-arc transition for a wide range of operating conditions. Accordingly, a stable glow discharge can be maintained with the cathode configuration of the present invention for a very wide range of operating pressures (up to atmospheric pressures) and in a wide range of electric field strengths.

Referring to **FIG. 1**, which shows a DC embodiment, the cathode of the present invention, generally indicated at **10**, comprises a metal cathode **20** (aluminum, stainless steel, etc.), covered with a perforated dielectric **30** positioned to face an upper electrode **40**. The perforated dielectric **30** may be retained on the cathode **20** by a collar **35** that fits over cathode **20** and has an aperture **36** therethrough, or may be formed as part of a cap or cover for the cathode **20**, or may be positioned thereon and held in place thereon in any other manner known in the art.

Importantly, the perforated dielectric can be formed of any desired dielectric type substance such as quartz, silicon nitride, silicon carbide, etc.. even glass. The dielectric is preferably formed of a material that can withstand high temperatures. Essentially, a perforated dielectric comprises a sieve of holes of micron dimensions. The center to center distance of the holes is of the same level of dimension. Hole dimensions are critical for particular applications. In trials discussed hereinafter, a dielectric having 10 micron holes with a center to center distance between the holes of 12 microns was used. Hole dimensions can vary from 5 to 200 μm for the hole diameter and from between 100μm to 2 mm for the hole length (thickness of the dielectric). Importantly, the ratio of the hole diameter to the dielectric thickness is an important factor and something that can be controlled depending upon the application. One example of such a ratio could be 10 to 1, the hole diameter being one-tenth of the thickness of the dielectric.

The perforated dielectric can be made by laser ablation. Blanks for dielectric plates made by Norton International can be used, and function in a desirable matter (a dielectric having a hole diameter of 10 μm, and a hole length of 0.6 mm). The hole diameter, hole lengths, hole density, and material can be varied to optimize the invention for a particular application. Any silicon carbide wafer can be perforated by laser ablation to form a perforated dielectric for use in connection with the present invention.

Referring to **FIG. 2**, shows a circuit that has been used to conduct trials of the present invention that will hereinafter be discussed, which can be used with the cathode configuration of the present invention to effect a stable DC glow plasma discharge. The circuit is governed by equation (1):

$$V_s = I_1 (R_1 + R_2) = \frac{1}{R_1} (R_1 + R_2)V \qquad \text{Equation (1)}$$

where $I_2=4I$

$$R_E \approx \frac{R_3}{4} \quad (\text{for } R_1 << R_3)$$

$$V_g = V_s - I_g R_3$$

$$V_d = V_s - I_d R_3$$

In this way, by measuring voltage V across resistor R, and current i through resistor R_1, we can calculate the voltage and the current across the cathode 10.

The present invention allows DC glow discharges, which have a well known instability that limits the operating range, to operate at much higher pressure up to atmospheric pressures. Accordingly, this stabilization allows for applications in many aspects of material processing, pollution remediation, novel lighting devices, and discharge-enhanced combustion.

The perforated dielectric covering the metal cathode stabilizes the cathode fall region of the DC discharge by breaking the discharge up into a large number of separate micro-channels. Each of the holes comprising the perforated dielectric acts as a separate, active current-limiting micro-channel. Particle losses due to wall effects and the finite volume of each channel place an upper limit on the electrical conductivity of each channel, and therefore place an upper limit on the current density that it can carry. This prevents the current density from increasing above the threshold for the glow-to-arc transition.

Additionally, it should be noted that a dielectric material could be directly deposited in a proper geometry directly onto a cathode by a vapor deposition or other process to apply the dielectric directly to the cathode. In this way, the cathode itself becomes an active current-limiting device.

A prototype DC glow discharge apparatus was set up using a parallel plate electrode arrangement in an Argon atmosphere of between 10-100 Torr, to illustrate the present invention. At these pressures, the phases of the glow-to-arc transition can be readily shown because the transition is sufficiently slow. The transition at atmospheric pressures occurs very rapidly and is difficult to observe. However, it should be pointed out that the present invention is designed to be used at pressures up to atmospheric pressures. Current voltage characteristics were recorded for a variety of operating conditions using a standard metal (Al) cathode. The measured curves show the well-known first transition corresponding to the breakdown of gas in the formation of a stable glow discharge, followed by a prominent second transition characteristic of the transition from the glow regime to an arc which creates a filamentary (high current density) channel. Subsequently, the conventional cathode was replaced by the new cathode design and the same current-voltage curves were recorded. All curves showed only the first transition to the stable high-current glow. No indications of the previously observed glow-to-arc transition were found under any operating conditions. The spatial distribution of the discharge is also diffuse.

Referring now to **FIG. 3**, a graph of voltage vs. current for applied voltage (VG), glow voltage (Vg) and arc voltage (Vd) is shown for Argon at 40 Torr. **FIG. 4** shows a graph of voltage

vs. current for applied voltage (VG), glow voltage (Vg), and arc voltage (Vd) in Argon at 20 Torr.

FIGS. 5a and **5b** are graphs of the applied voltage and glow-to-arc voltage with and without the perforated dielectric of the present invention. These figures show the stabilization of the glow plasma discharge. In a first Stage A, there is no current. In the second Stage B, voltage is applied, but current stays at zero. In a third Stage C, a glow discharge is achieved. As seen in **FIG. 5a**, the glow quickly goes to arc D, while in **FIG. 5b**, the perforated dielectric suppresses the glow-to-arc transition and stabilizes the glow discharge such that there is no arc.

FIG. 6a is a photograph showing an arc discharge which creates a filamentary (high current density) channel. **FIG. 6b** is a photograph showing a glow discharge characterized by a uniform glow discharge.

FIG. 7 is a side plan view of an RF discharge embodiment of the present invention wherein the perforated dielectric is positioned over both electrodes. As can be seen electrodes **120** and **140** are both covered by a perforated dielectric **130**. Because the current reverses itself in a RF electric field, the dielectric **130** must be positioned over both electrodes **120** and **140**, as both electrodes alternately serve as cathodes. By this configuration, the glow discharge can be sustained under broader operating conditions. Such a configuration results in a frequency independent and size independent device.

By applying the method and apparatus of the present invention to large volume plasmas at atmospheric pressures, it is possible to increase the energy released during combustion of fuels to levels several times higher than the Heating Value of the fuel. Efforts in this area in the past have failed because the distribution of energy is required over a substantial volume and cannot be concentrated in a small area. Because of the glow-to-arc transition, there has been tendency to produce arcs of a very high energy level with the rest of the volume remaining at a normal combustion level. By suppressing the glow-to-arc transition and stabilizing the plasma glow, the method and apparatus of the present invention overcomes the limitations of the prior attempts and results in an enhancement of the combustion process resulting in much higher energy densities than

could be previously achieved.

Additional applications of the present invention may occur in the field of air pollution remediation where stabilization of the glow-to-arc transition may result in real time destruction of constituents of air emissions from manufacturing operations in remediation of soil and ground water pollution, in large volumes at high pressures. By suppressing the glow-to-arc transition and stabilizing the glow discharge, the present invention creates large volume plasmas to destroy the polluting vapors at higher efficiencies with reduced cost. There could be additional applications relating to the destruction of combustion by-products such as NO_x and SO_x which have heretofore been destroyed by pulsed corona and barrier discharges.

The present invention is additionally applicable to the cleaning of lithography sheet surfaces in atmospheric pressures. Additionally, there may be possible utility for large area surface cleaning at atmospheric pressure for curing polymer films. By being able to operate at atmospheric pressure, a great advantage is achieved over the high processing cost required in a vacuum process. Additionally, the present invention can be used for pretreatment of semi-conductors, glasses, and polymers which are to be used for direct metal ion beam processing.

Additionally, an atmospheric pressure glow discharge plasma can be used to sterilize biologically contaminated surfaces. Current techniques in this area utilize high temperatures, strong chemicals, and/or ultraviolet radiation to sterilize contaminated items. However, there are problems with these approaches in that the processes are time intensive and potentially hazardous and result in the formation of potentially hazardous by-products. It has been demonstrated that materials exposed to a one-atmosphere pressure glow discharge plasma can be sterilized of biological contaminants in under one minute.

Having thus described the invention in detail, it is to be understood that the foregoing description is not intended to limit the spirit and scope thereof. What is desired to be protected by the Letters Patent is set forth in the appended claims.

CLAIMS

What is claimed is:

1. A glow plasma discharge apparatus for generating and maintaining a glow plasma discharge comprising:

a pair of electrodes positioned in facing relation having a space there between;

a perforated dielectric having a plurality of apertures of micron dimension placed over one of the electrodes and partially occupying the space; and

an electric field generated between the electrodes.

2. The apparatus of claim 1 wherein the perforated dielectric comprises a plurality of apertures, each aperture having a diameter ranging from 5 to 200μm.

3. The apparatus of claim 2 wherein the dielectric is between 100μm and 2mm in thickness.

4. The apparatus of claim 1 wherein the dielectric comprises silicon nitride.

5. The apparatus of claim 1 wherein the dielectric comprises silicon carbide.

6. The apparatus of claim 1 wherein a second dielectric is placed over the other of the electrodes.

7. The apparatus of claim 1 wherein the dielectric is a high temperature dielectric able to withstand high temperatures.

8. A cathode in a glow plasma discharge apparatus for generating and maintaining a glow plasma discharge comprising:

an electrode;

current limiting means having a plurality of apertures of micron dimension placed over the electrode for limiting current density associated with the electrode; and

means for retaining the current limiting on the electrode.

9. The apparatus of claim 8 wherein the apertures have a diameter ranging from 5 to 200μm.

10. The apparatus of claim 9 wherein the current limiting means is between 100μm and 2mm in thickness.

11. The apparatus of claim 8 wherein the current limiting means comprises silicon nitride.

12. The apparatus of claim 8 wherein the current limiting means comprises silicon carbide.

13. The apparatus of claim 8 wherein a second current limiting means is placed over the other of the electrodes.

14. The apparatus of claim 8 wherein the current limiting means is a high temperature dielectric able to withstand high temperatures.

15. A glow plasma discharge apparatus for generating and maintaining a glow plasma discharge comprising:

a pair of electrodes positioned in facing relation;

an electric field generated between the electrodes; and

a dielectric having a plurality of apertures of micron dimension positioned between the electrodes, the apertures sized to limit current density between the electrodes from increasing above a pre-determined threshold.

16. The apparatus of claim 15 further comprising collar means for retaining the dielectric on one of the electrodes.

17. The apparatus of claim 15 wherein the dielectric is formed integrally with one of the electrodes.

18. A method of generating and maintaining a glow plasma discharge comprising the steps of:

positioning opposing electrodes in a facing relation with a space therebetween;

providing within the space a perforated dielectric having a plurality of apertures of micron dimension; and

generating an electric field between the electrodes.

19. The method of claim 18 further comprising the step of providing a second perforated dielectric having a plurality of apertures of micron dimension within the space.

20. The method of claim 18 wherein the step of positioning the perforated dielectric with the space further comprises placing the perforated dielectric on an electrode and retaining the dielectric thereon.

21. The method of claim 20 wherein the step of retaining the dielectric on one of the electrodes further includes the step of placing a retaining collar over the dielectric.

22. The method of claim 18 wherein the step of positioning the perforated dielectric within the space comprises the step of depositing a dielectric on one of the electrodes.

23. The method of claim 22 wherein the step of depositing a dielectric on one of the electrodes comprises vapor deposition.

FIG. 1

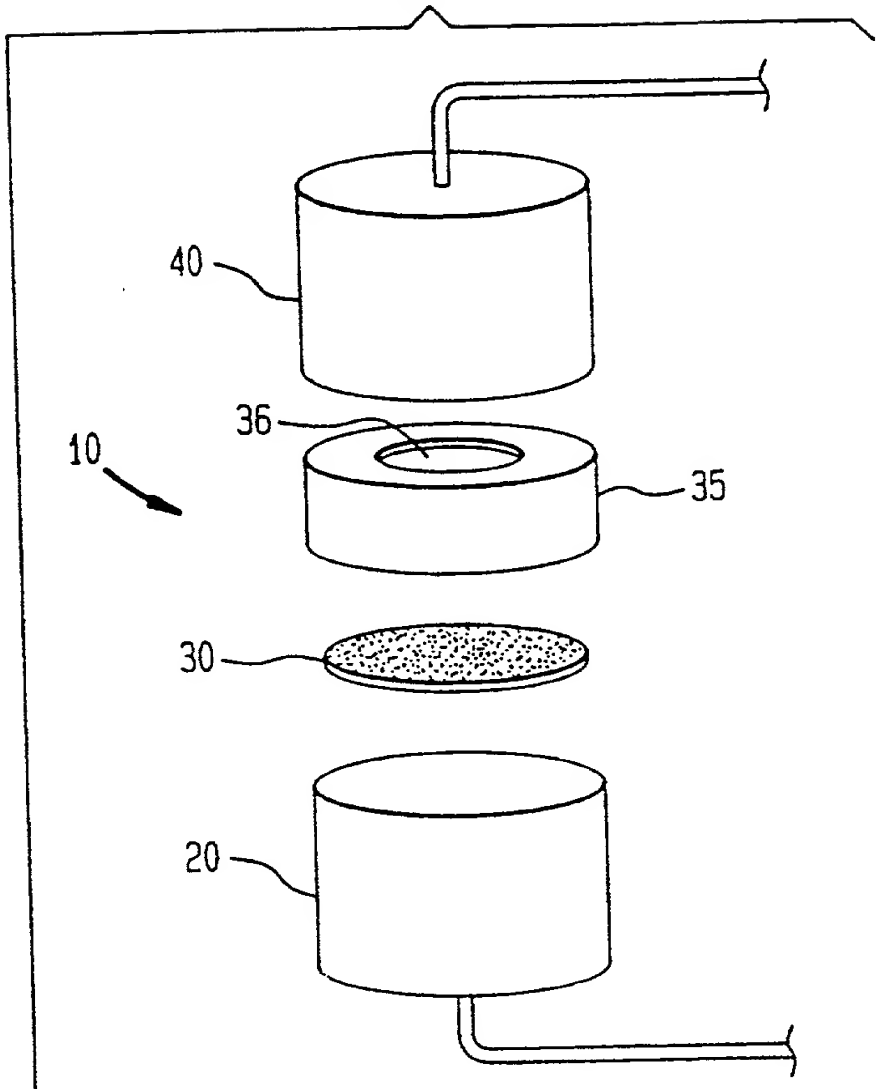

40
36
10
35
30
20

FIG. 2

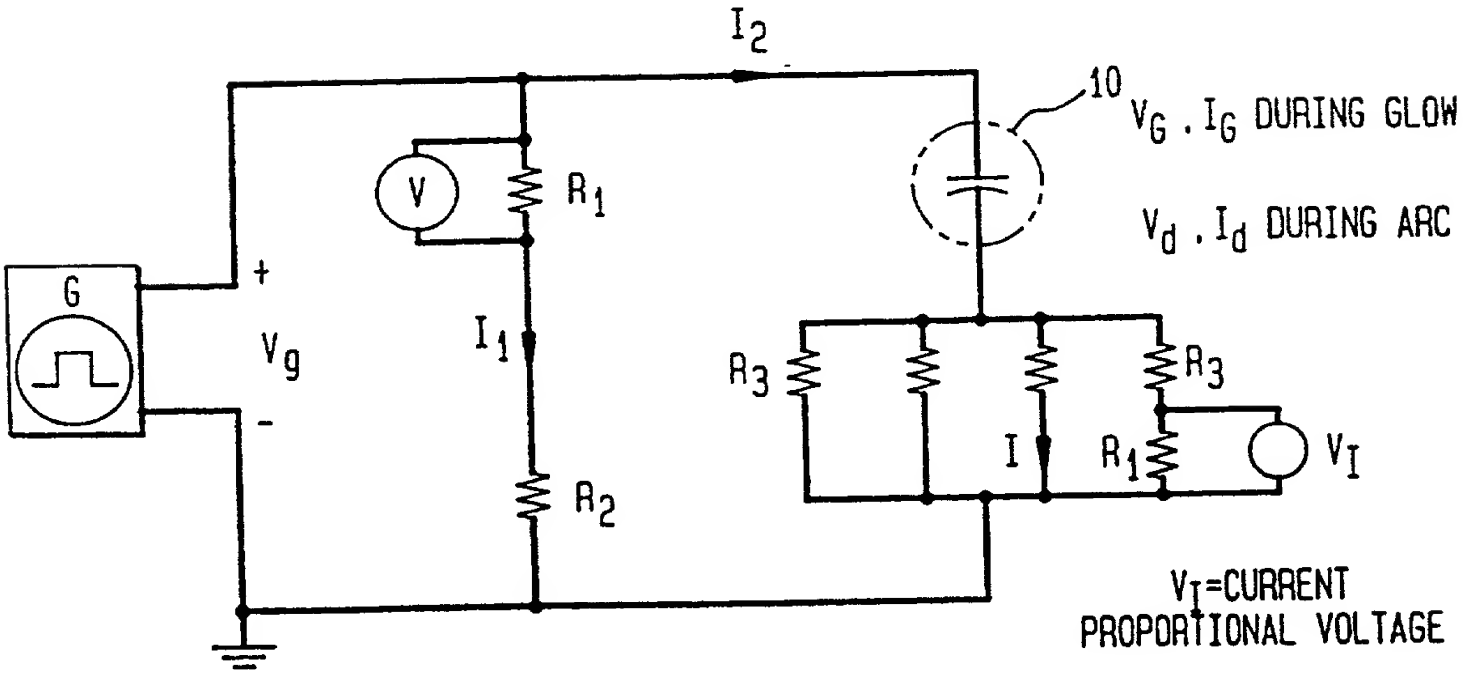

I2
10
VG . IG DURING GLOW
Vd . Id DURING ARC
V
R1
G
+
Vg
-
I1
R2
R3
R3
I
R1
VI
VI=CURRENT
PROPORTIONAL VOLTAGE

FIG. 3

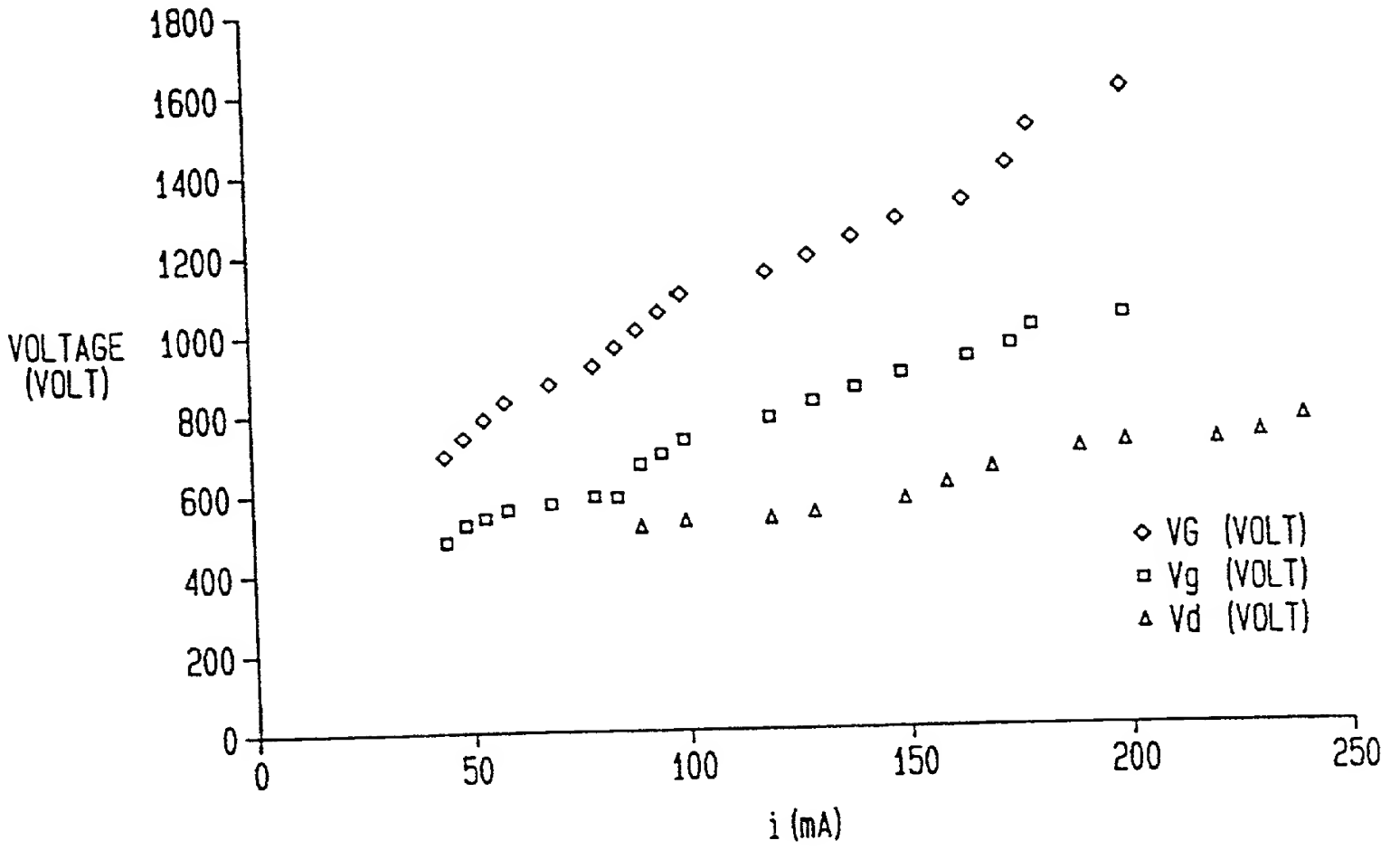

1800
1600
1400
1200
1000
800
600
400
200
0
VOLTAGE (VOLT)
0
50
100
150
200
250
i (mA)
VG (VOLT)
Vg (VOLT)
Vd (VOLT)

FIG. 4

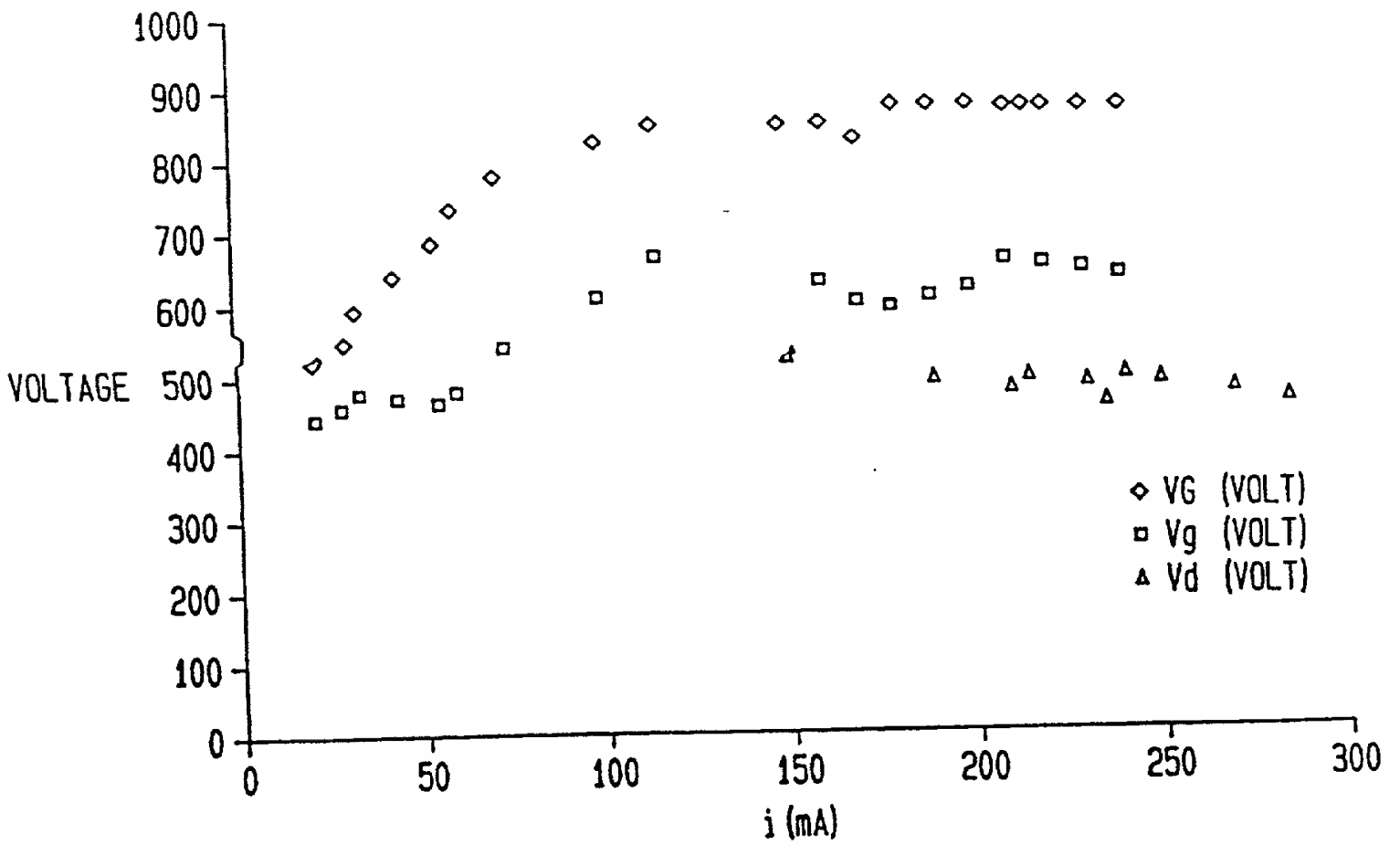

1000
900
800
700
600
500
400
300
200
100
0
VOLTAGE
0
50
100
150
200
250
300
i (mA)
VG (VOLT)
Vg (VOLT)
Vd (VOLT)

FIG. 5A

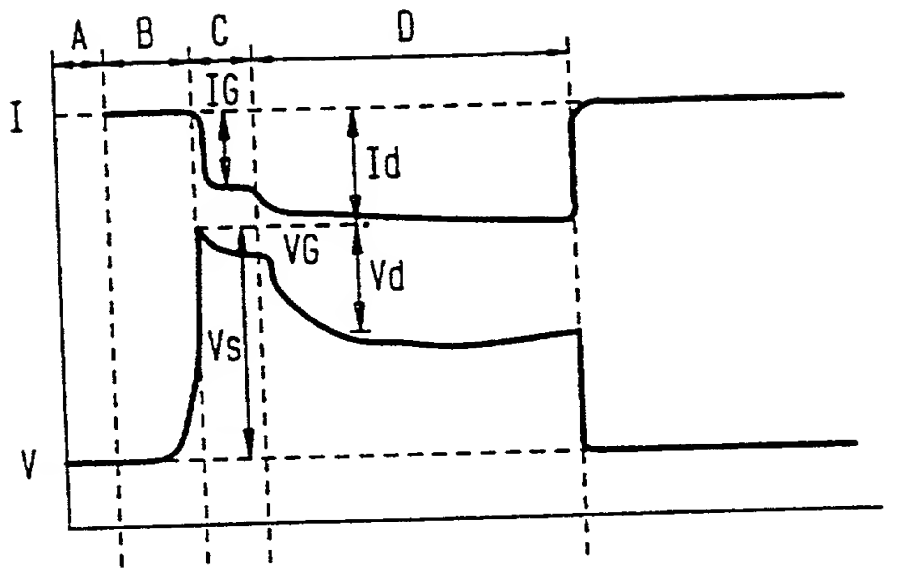


FIG. 5B

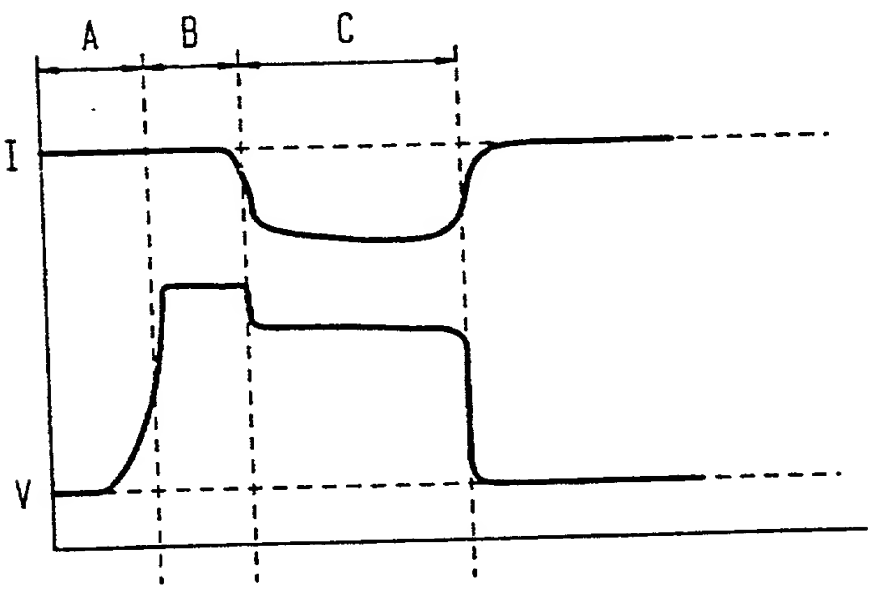


FIG. 7

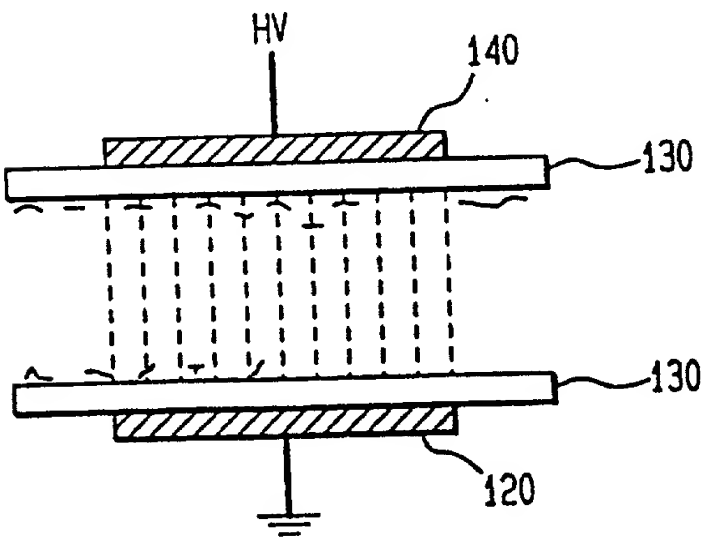
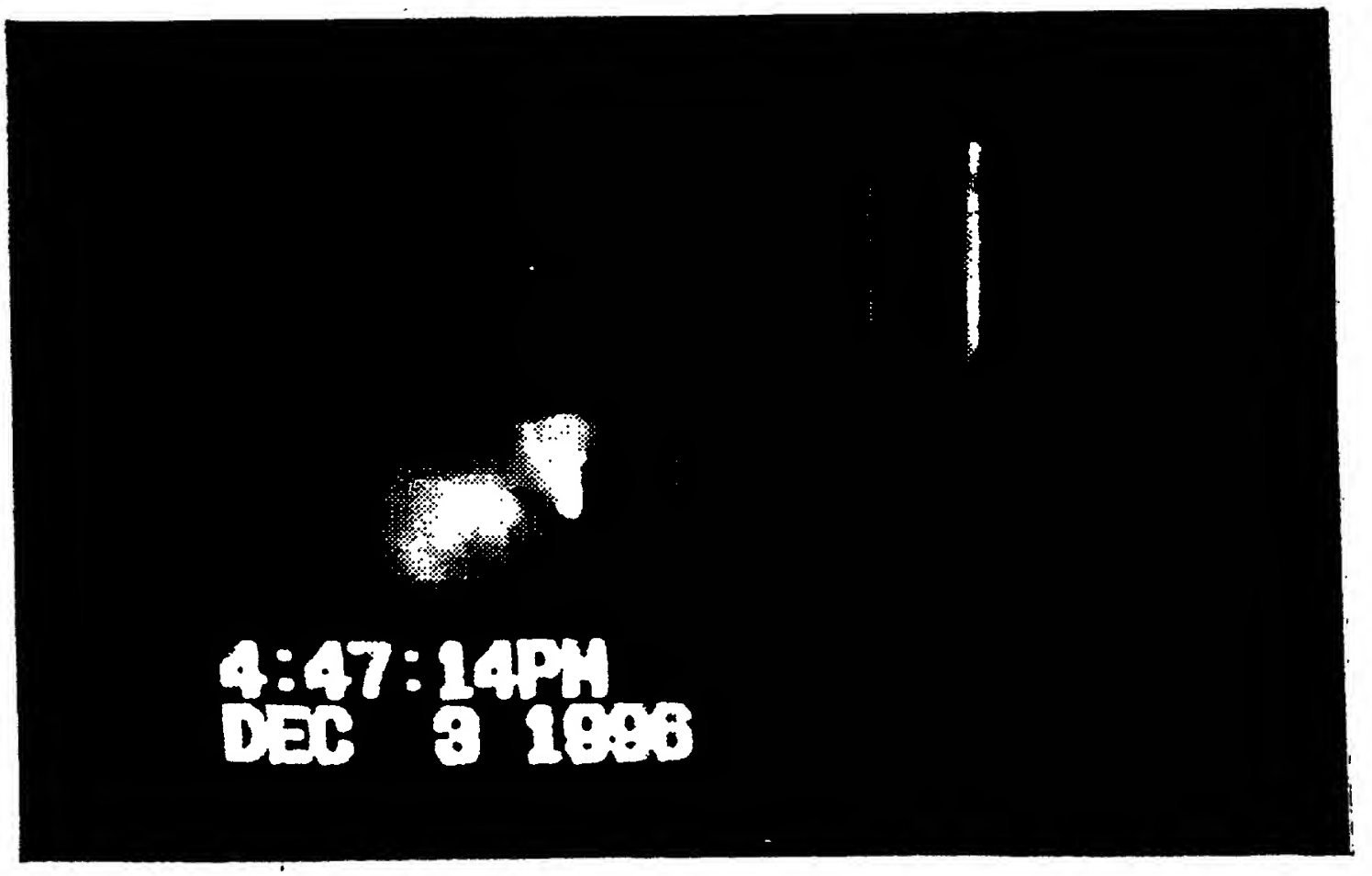


FIG. 6A

FIG. 6B



DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

TYPE OF DECLARATION

This declaration is of the type:

___ original
___ design
___ supplemental

_X_ national stage of PCT

___ divisional
___ continuation
___ continuation-in-part (CIP)

INVENTORSHIP IDENTIFICATION

My residence, post office address and citizenship are as stated below next to my name. I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

TITLE OF INVENTION

METHOD AND APPARATUS FOR SUPPRESSION OF THE GLOW-TO-ARC TRANSITION IN GLOW DISCHARGES

SPECIFICATION IDENTIFICATION

the specification filed on March 17, 1998 and assigned Serial No. PCT/US98/05174.

ACKNOWLEDGEMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37, Code of Federal Regulations, 1.56, and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable examiner would consider it important in deciding whether to allow the application to issue as a patent.

PRIORITY CLAIM

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent of inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

___ no such applications have been filed.
_X_ such applications have been filed as follows.

PRIOR FOREIGN/PCT APPLICATIONS FILED WITHIN 12 MONTHS
(6 MONTHS FOR DESIGN) PRIOR TO THIS APPLICATION
AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119

COUNTRY	APPLICATION NUMBER	DATE OF FILING	PRIORITY

ALL FOREIGN APPLICATION(S), IF ANY FILED MORE THAN 12 MONTHS
(6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION

I hereby claim the benefit under Title 35, United States Code, 120, of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, 1.56(a), and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable examiner would consider it important in deciding whether to allow the application to issue as a patent, which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NO.	FILING DATE	STATUS
08/820,013	03/18/97	Pending

POWER OF ATTORNEY

I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE(S)

1-00

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This declaration ends with this page.

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